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Economic impacts of natural gas flow disruptions between Russia and the EU

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ABSTRACT

In this paper we use a non-linear programming approach to predict the wider interregional and interindustry impacts of natural gas flow disruptions. In the short run, economic actors attempt to continue their business-as-usual and follow established trade patters as closely as possible. In the model this is modelled by minimizing the information gain between the original pattern of economic transactions and the situation in which natural gas flows are disrupted. We analyze four scenarios that simulate Russian export stops of natural gas by means of a model calibrated on an international input-output table with six sectors and six regions.

The simulations show that at the lower levels of aggregation considerable effects are found. At the aggregate level of the whole economy, however, the impacts of the four scenarios are negligible for Europe and only a little less so for Russia itself. Interestingly, the effects on the size of the economy, as measured by its GDP, are predominantly positive for the various European regions, but negative for Russia. The effects on the welfare of the populations involved, however, as measured by the size of domestic final demand, have an opposite sign; with predominantly negligible but negative effects for European regions, and very small positive effects for the Russian population.

1. Introduction

In aiming to ensure a resilient energy system, the European Union (EU) initiated an extensive energy policy package (European Commission, 2015). Natural gas is given an important role in meeting future EU-wide energy demand. It can be flexibly produced and stored, and therefore represents a good backup for intermittent renewable energy. Significant natural gas demand growth and demand variability is foreseen, especially for certain regions (Smith, 2013). Due to dwindling EU natural gas reserves, dependency on non-EU gas flows will increase. Anticipating these developments, multiple far-reaching measures have been taken in order to arrive at a single well-functioning internal gas market. The continuing integration of the gas market also contributes to larger gas flows across all EU countries.

Russia is one of the main suppliers of natural gas to the EU-market (International Energy Agency, 2014). Russia exports its natural gas to Europe via pipelines, which requires crossing the territory of third countries, like Ukraine. Over the years, problems between Russia and Ukraine have had their impact on natural gas flows to the EU. The 19-day complete disruption of transit flows via Ukraine at the start of 2009 has been the worst incident so far (see Pirani et al. (2009) for details). It impacted consumers in several East European countries, mainly through problems with district heating, but the alleged impact on industrial output could not be separated from other possible causes of change (Kovacevic, 2009). On January 20th of that year, supply was reinstated after signing a 10-year transit contract; the current transit contract between Gazprom, Russia's main natural gas producer and monopolist of pipeline exports, and Naftogaz, owner of the pipelines in Ukraine. This contract will thus end in 2019. Although both the European Union and Russia have been working on diversifying the transit routes, the reliance on Ukrainian transit capacity will still be sizeable in 2019, which may again lead to problems (Pirani and Yafimava, 2016).

On the other hand, Russia is also actively pursuing strategies to diversify away from Europe and to generate gas export revenues elsewhere (Dickel et al., 2014; Shadrina, 2014). The focus is currently on developing gas fields in East Siberia for East Asian markets. Over the past years demand from this region has increased, resulting primarily in the development of LNG investment projects (Motomura, 2014). Even though the recently agreed contract with China includes building a pipeline called the ‘Power of Siberia’, that is currently being constructed, it is not expected to be operational before

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2020 (International Energy Agency, 2014).[1] In addition, this pipeline will not directly compete with exports to Europe, as it is built east of Mongolia and does not connect to the European network.

The pipeline that would allow Russia to alternate gas flows between Europe and China, to be build west of Mongolia through the Altai Republic, however, only represents a sketchy plan (Dickel et al., 2014). Russia's advancements over the years have been very haphazard for several reasons, among which the global economic crisis, technical difficulties in developing these East Siberian fields, and lengthy negotiation processes (Fernández and Palazuelos, 2011; Henderson and Stern, 2014). Still, with subsequent energy strategies, Russia has become more positive about the share of gas that will be exported to East Asia, reaching over 30% by 2035 (Shadrina, 2014). Paltsev (2014) has confirmed the feasibility of this scenario using a modelling approach. Impacts on the European market, in terms of diversion of flows elsewhere, however, are likely to be limited, although Russia may be able to take a stronger bargaining position after 2050 (Orlov, 2016).

The renewed Ukraine-Russia turmoil over the past years has again increased the tension between the EU and Russia. Alternative routes, via Belarus (Yamal pipeline) or via the Baltic Sea (Nord Stream pipeline) offer spare capacity, but not enough to fully replace transit flows through Ukraine (Pirani and Yafimava, 2016). The European Commission has published a reinforced energy security strategy, focusing on more resolute actions to diversify supply and strengthen the internal infrastructure in order to promote resilience to disruptions (European Commission, 2014a). This strategy is a response to mitigate the EU's dependence on Russia as natural gas supplier and on Ukraine as main transit country. To assess EU's vulnerability to Russian gas supplies, the European Commission has, furthermore, undertaken a stress test to see whether the EU would be able to get through a winter without any imports from Russia. The sources expected to contribute most to the alternative supply of natural gas are Norway, LNG, and underground storage facilities in the EU. Only in case all Member States cooperate, no household would have to be affected. The Eastern Member States and former Yugoslavian countries would be affected most (European Commission, 2014b).

Ex-post modelling of the 2009 Ukraine incident showed that, given the available infrastructure and storage, the European gas industry dealt with the crisis in nearly the best possible way (Lochner, 2011). The mild winter and the economic crisis had caused storage levels to be higher than usual, which mitigated the impact of the crisis. Still, a small increase in the flexibility of pipelines, i.e., making reverse flows possible, would have significantly improved the security of supply in Eastern Europe. Richter and Holz (2015) show that the average impact on the EU would be limited to slightly higher prices, at least in their short term disruption scenarios. Again, certain East European countries are much more severely affected. The long term disruption scenario has much more impact. The authors see an important role for LNG, although large investments in transportation infrastructure would be needed to accommodate these flows. Egging and Holz (2016) investigate a scenario in which transit of Russian gas via Ukraine is disrupted from 2020. Again, the role of LNG is confirmed, and the authors remark that Poland has started to become a transit hub. Interestingly, Egging and Holz (2016) also claim that China will be dominating the global natural gas market in the future in all their scenarios, even despite the possibility of significant climate policy efforts that may be undertaken (Holz et al., 2015).

The strong international dimension of the gas market implies that any supply shock will be propagated extensively through the network. Not only in terms of the physical flows of natural gas, but also in terms of the economic impact of gas flow disruptions. In this paper, we investigate the *wider economic* impacts of disruptions in the supply of natural gas with a *new approach*. A non-linear programming model is used to predict the short and medium term interregional and inter-industry impacts of four disruption scenarios. In the model, these impacts are determined by the hypothesized attempts of economic actors to continue their business-as-usual, as much as possible, by staying as close as possible to their established trade patterns. This behavioral response to a disruption is implemented by minimizing the difference between the pre- and the post-disruption pattern of economic transactions.

Several scenarios will be analyzed based on data from the EXIOPOL international input-output database (see Tukker et al. (2013)), because this database includes a separate natural gas extraction sector. The set of scenarios we study focuses on the fact that Russia may decide to stop the export of natural gas. This could be a total ban on all exports to the EU, in its most extreme form. More realistically, it may be a setting in which only particular cross-border flows are hampered. For example, physical pipelines may be damaged, or Russia may decide to limit cross-border flows to certain European regions for political reasons. These situations will be simulated by reducing or removing the economic transactions related to the flows of natural gas between countries. Limited changes in gas supply can be accommodated by the gas infrastructure of the EU, because of redundant capacity for security of supply reasons. However, due to limited transport capacity, or limited possibilities to extract additional gas, natural gas quantities that can be supplied in the short and medium run will be limited.

Our type of analysis of the economic impacts of natural gas flow disruptions will inform policy makers on the order of magnitude of the wider economic impacts from disruptions in the supply of natural gas. The results also identify critical gas supplier relations for the economic functioning of the Member States and strains on the rest of the economic system following a gas supply disruption. Our type of approach could also be used to further investigate mitigation strategies, such as diversifying supply or investing in additional infrastructure.

2. Modelling methodology, data and scenarios

The model used mimics that, in the short run, economic actors attempt to continue their business-as-usual, and attempt to follow established trade patters as closely as possible. This behavior is simulated by minimizing the information gain between the original pattern of economic transactions between all industries and all regions distinguished, as shown in the base year interregional input-output table (IRIOT) at hand, and the situation in which the flow of natural gas is disrupted, as captured by the measure originally proposed by Kullback (1959) and Theil (1967). Here, we use a slightly adapted version of the information measure that is referred to as IGRAS (Huang et al., 2008). Our type of model was first set-up to analyze the impact of natural disasters (Oosterhaven and Bouwmeester, 2016, see also Koks and Thissen, 2016), but it is also suited to simulate the impacts of trade boycotts. See Oosterhaven (2017) for the reasons of choosing this modelling approach above, e.g., the standard extended input-output (IO) model, the inoperability IO model or the hypothetical extraction method.

Our modelling approach focuses on all economic relations for the entire economies of the regions included, which allows us to analyze the impact of the disruption scenarios for the entire economy. Other models used in the literature for disruption analysis concentrate on the natural gas production sector and/or the natural gas transport infrastructure. The TIGER model, used by Lochner et al. (2010) and Lochner (2011), is a linear optimization network flow model that minimizes the cost of natural gas demand satisfaction, constrained by the available capacities of over a thousand infrastructure elements. The Global Gas Model is a partial equilibrium model set up as a large-scale mixed complementarity problem, with high detail on storage and transportation infrastructure (Richter and Holz, 2015); a stochastic variant also exists (Egging and Holz, 2016). The model solves for long-

[1] See also: http://neftegaz.ru/en/news/view/154118-Gazprom-s-Power-of-Siberia-pipeline-set-for–2020-launch.

term cost-efficient equilibria. Focusing on the infrastructure, GEMFLOW is a model representing an interconnected regional gas system that gives an overview at the country level of the reaction to a disruption event by the user. The model applies a Monte Carlo approach to identify the scenarios with the longest operability of the system or with the smallest loss in natural gas consumption (Szikszai and Monforti, 2011). Due to our focus on an economy-wide approach, our model does not include capacity limits of the current physical transport infrastructure. Still, by remaining as close as possible to the current economic flows, which have been realized with the current infrastructure, we believe we can realistically sketch the economy-wide impacts.

2.1. Base model

The objective function of the model minimizes the information loss of the disrupted IRIOT compared to the base year IRIOT:

$$\textit{Minimize } \sum\nolimits_{r,s,i,j} z_{ij}^{rs}[\ln(z_{ij}^{rs}/z_{ij}^{rs,ex}) - 1] + \sum\nolimits_{r,s,i} y_{i\bullet}^{rs}[\ln(y_{i\bullet}^{rs}/y_{i\bullet}^{rs,ex}) - 1] + \\ + \sum\nolimits_{s,j} v_j^s[\ln(v_j^s/v_j^{s,ex}) - 1], \tag{1}$$

where the variables are: z=intermediate demand, y=final demand, excluding changes in inventories and valuables, and v=value added at market prices (GDP). Excluding changes in inventories implies that our model does not include the ultra-short term mitigating effects of using natural gas from storage sites. Instead we focus on the short to medium term (say multiple months) impacts of disruptions in the cross-border flows of natural gas. The indices i and j indicate industries of origin and destination, and r and s regions of origin and destination, respectively. A $\bullet$ represents the summation over an index, and ex stands for exogenous, i.e., for the actual values from the base year IRIOT.

The objective function (1) is minimized subject to a number of constraints. First, all economic transactions are restricted to have either a zero or a positive value, i.e., all variables in (1) are to take semi-positive values only (see Oosterhaven and Bouwmeester, 2016, for a further discussion).

Second, we assume cost minimization under a Walras-Leontief production function, per input, per industry, per region, which results in (Oosterhaven, 1996):

$$\sum\nolimits_r z_{ij}^{rs} = a_{ij}^{\bullet s} x_j^s \text{ and } v_j^s = c_j^s x_j^s, \forall\ i, j, s \tag{2}$$

Where additionally x=total output, a=intermediate inputs per unit of output, and c=value added per unit of output, where a and c are calculated from the base year IRIOT as $a_{ij}^{\bullet s} = \sum_r z_{ij}^{rs,ex}/x_j^{s,ex}$ and $c_j^s = v_j^{s,ex}/x_j^{s,ex}$, with $\sum_i a_{ij}^{\bullet s} + c_j^s = 1$. Note that (2) excludes the possibility of technical substitution, e.g., of coal for natural gas, but does allow for spatial substitution, e.g., of natural gas from one origin region for that from another origin region.

Thirdly, we assume that prices, which in our approach do not need to be modelled explicitly, do change is such a way that all markets are in short run equilibrium, i.e., that demand equals supply, per industry, per region:

$$\sum\nolimits_{s,j} z_{ij}^{rs} + \sum\nolimits_s y_{i\bullet}^{rs} = x_i^r,\ \forall\ i, r. \tag{3}$$

Table 1
Regions and sectors represented in the model.

Regions	Sectors
North-West Europe	Primary
South-West Europe	Natural gas extraction
East Europe	Other energy extraction
North-East Europe	Secondary
Russian Federation	Electricity from gas
Rest of the World	Tertiary

Not needing to model prices explicitly, is a great simplifying advantage of our approach. Note that (2) and (3) combined ascertain that total input equals total output, per industry, per region, which implies that any solution of (1)–(3) satisfies the IRIOT accounting identities.

In the specific case studied here, i.e., that of natural resource extraction, the production of additional output is restricted by existing reserves. Our last restriction, therefore, specifies our estimate of the natural gas production restrictions by region.

$$x_i^r \le x_i^{r,\max},\ \forall\ i, r. \tag{4}$$

The above non-linear programming approach (1)–(4), thus combines the assumption of fixed technical coefficients with flexible trade coefficients. This implies that (partial) import and export substitution (cf. Oosterhaven, 1988) is considered to represent a realistic reaction to supply shocks to the flows of natural gas.

2.2. Data

The input-output database used has been constructed during the EXIOPOL project (Tukker et al., 2013).[2] The full database contains 43 countries and 129 sectors. For this first empirical application of this new model, we have aggregated the data to six sectors and six regions. The sectors and regions represented are given in Table 1. In Appendix A the concordances with the original data are given. The different categories of value added per sector have been combined with the data on taxes less subsidies per sector, resulting in one value (gross value added measured at market prices) that represents each sector's contribution to GDP. In the remainder of this paper, we refer to this single value simply as “value added”.

The focus of our study is on the European Union. Its countries have been divided into four regions primarily based on their geographical location and the layout of the main natural gas pipelines, and secondarily based on their position in the gas market. Of all non-EU countries, we have kept the Russian Federation as a separate region, due to its important role in the supply of gas to the European market. All countries outside the European Union and Russia have been combined into one large region called ‘Rest of the World’. The grouping of countries is visually represented in Fig. 1.

With respect to the sectors, we have kept two single sectors from the extensive set of sectors represented in the full EXIOPOL database. These are the natural gas extraction sector and that part of the electricity sector that is fueled by natural gas. The natural gas extraction sector will allow us to look at the specific effects of changes in the supply of natural gas. The electricity from gas sector is fully dependent on the supply of natural gas and is directly harmed by a reduction in the supply of natural gas. The third small sector, other energy extraction, is an aggregation of all other individual energy extraction sectors that are present in the EXIOPOL database. This sector may function as a substitute for natural gas extraction in an indirect sense. Given the Leontief technology assumption in Eq. (2), natural gas inputs cannot be directly substituted. However, sectors in different countries may rely on different energy sources. Consequently, the output of such a sector may be substituted for the output of a sector that relies on natural gas, which represents an indirect type of substitution. This potential coping mechanism is not considered in the other models used in the literature. The remaining sectors are aggregated into a primary sector representing agriculture, forestry and fishing, a secondary sector representing manufacturing, and a tertiary sector representing services.

Europe's capacity to produce additional natural gas domestically is

[2] The data are publicly available via the website exiobase.eu. For this study EXIOBASE 1 (year 2000) was used, as the follow-up IRIOT was not available at the time this analysis was undertaken.

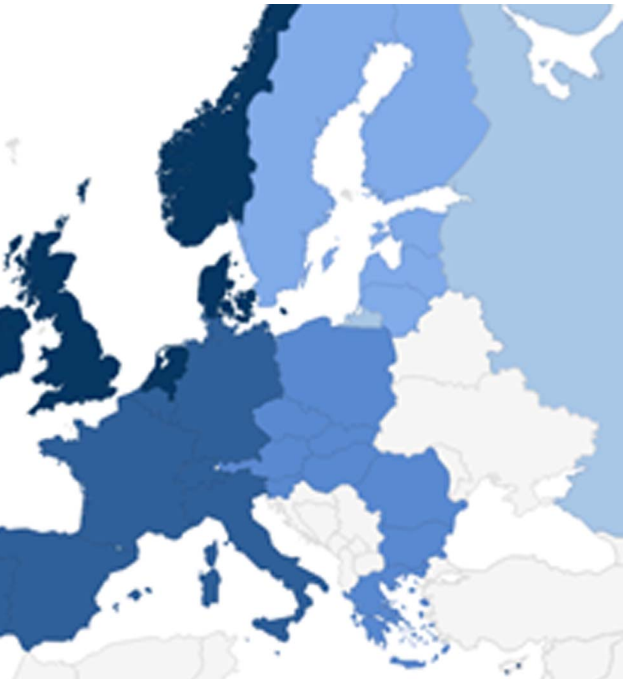

Fig. 1. Grouping of EU countries into regions.

Table 2
Natural gas production capacity constraints.

Region	Additional production capacity
North-West Europe	15%
South-West Europe	10%
East Europe	10%
North-East Europe	0%
Russia	50%
Rest of the World	100%

severely limited due to limited reserves. To include this in the model, all scenarios are implemented with constraints on additional production, as indicated in Eq. (4). The percentages for North-West Europe and for the Rest of the World have been derived from European Commission (2014b). The percentages for the other regions are set in relation to their current production capacity and represent general estimates of what could additionally be produced given the present reserves. The output constraints used in our model are listed in Table 2.[3] In the future, these production capacities may increase due to the production of unconventional gas, which would also impact international gas flows. Osička et al. (2016), for example, describe how the production of unconventional gas in Poland would significantly impact regional natural gas flow patterns if it would become a success.

2.3. Scenarios

To study the economic impacts of disruptions in the flows of natural gas, we have defined four scenarios. All scenarios focus on Russia due to its role as single most important supplier of natural gas to the EU economy. In the first scenario Russian exports to all European countries are stopped, in the second only its exports to North-East Europe, in the third only its exports to East Europe, and in the fourth only its exports to North-West and South-West Europe. The first scenario thus constitutes the combination of the latter three. Each scenario is formed by adding the following Scenario-specific equation to the Base scenario (1)–(4):

$$\sum_{j}^{rs \in \text{Scenario x}} z_{ij}^{rs} + y_{i.}^{rs} = 0\ , \quad \text{for } i = \text{ natural gas extraction} \tag{5}$$

The different scenarios are shown in Table 3. A list of the specific countries belonging to the different regions can be found in Appendix A.

Table 3
Natural gas disruption scenarios.

Scenario	Region imposing export ban:	On its natural gas exports to:
1	Russian Federation	All four EU regions
2	Russian Federation	– North-East Europe
3	Russian Federation	– East Europe
4	Russian Federation	– South-West Europe and North-West Europe

Although natural gas exports are not as important for the Russian economy as oil exports, fully cutting off the entire European market, as in Scenario 1, is likely to cause considerable damage to the Russian economy. Therefore, especially, Scenario 1 represents an extreme variant, which only means to establish the maximum economic effect that could follow from possible natural gas flow disruptions in Europe.

3. Results

3.1. Base scenario with natural gas dependencies

First, the base scenario, with which the natural gas disruption scenarios need to be compared, is set up. For this scenario we exclude the discrepancy column present in the IRIOT (Tukker et al., 2013) and we also exclude all changes in inventories and valuables. Both types of data do not represent actual economic transactions for which we assume that economic actors will try to maintain them as much as possible. The removal of these data results in an IRIOT in which supply no longer equals demand. In the base scenario, this equilibrium is restored using the base model, i.e., Eqs. (1)–(3). The specific functional form of the objective function can be used in this case, as all negatives are removed from the data.

To evaluate the resulting change in the IRIOT, the mean absolute percentage error (MAPE) and the weighted mean absolute percentage error (WAPE) are used.[4] The MAPE is found to be 387% and the WAPE is equal to only 0.11%, which indicates that the large percentage changes predominantly occur in the smallest cells of the IRIOT. The size of the world economy, as measured by world GDP, which relates to the largest cells, was equal to 34,009 billion Euros in the original IRIOT, whereas in the base scenario IRIOT the total is 34,002 billion euros (99.98% of the original total). Hence, we conclude that the base scenario IRIOT is sufficiently close to the original IRIOT to serve as the starting point for the scenario simulations.

Using the outcomes of the base scenario IRIOT, new coefficient matrices for $a_{ij}^{\bullet s}$ and c_j^s are calculated, which are used for the disruption scenarios. Also, all values with ex in Eq. (1) are replaced with the corresponding values of bm, where bm indicates the base scenario

[3] Note that our percentage for North-West Europe is conservative compared to Richter and Holz (2015), who assume a 15% slack production capacity for Norway and the Netherlands each. According to BP's Statistical Review of World Energy June 2016, both Poland and Romania have a reserve of 0.1 trillion cubic metres natural gas at the end of 2015. The reserve-to-production (R/P) ratio is 23.1 years for Poland and 10.7 years for Romania. Hence, we assume that in the short to medium run a production increase by 10% is possible for Eastern Europe. See: https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf.

[4] MAPE= $\sum_{i=1}^{n}\left|\frac{ex_i - bm_i}{ex_i}\right| * \frac{100\,\%}{n}$, and WAPE= $\frac{\sum_{i=1}^{n}|ex_i - bm_i|}{\sum_{i=1}^{n} ex_i}*100\%$, where ex_i represents the original IRIOT values, and bm_i represents the base model IRIOT values (i.e., z_{ij}^{rs}, v_i^{rs} and $y_{i.}^{rs}$).

Table 4
Russia's natural gas sector's role as supplier.

Region	Sector	Sales of Russian gas to a specific region-sector in million €	Sales to a region-sector as % of total output of the Russian gas[a]	Russian sales as % of total gas inputs per region-sector	Russian sales as % of total gas imports per region-sector
North-West Europe	Primary	0.1	0%	0%	8%
	Natural gas extract.	0.1	0%	0%	2%
	Other energy extr.	0.2	0%	0%	1%
	Secondary	1.4	0%	0%	2%
	Electricity from gas	0.3	0%	0%	2%
	Tertiary	0.2	0%	0%	1%
	Final demand	0.4	0%	0%	2%
South-West Europe	Primary	1.8	0%	4%	4%
	Natural gas extract.	0.4	0%	2%	5%
	Other energy extr.	0.9	0%	2%	5%
	Secondary	277.7	6%	4%	4%
	Electricity from gas	477.7	11%	7%	8%
	Tertiary	21.1	0%	2%	4%
	Final demand	73.2	2%	2%	4%
East Europe	Primary	2.1	0%	35%	41%
	Natural gas extract.	10.4	0%	18%	92%
	Other energy extr.	2.8	0%	12%	67%
	Secondary	514.9	12%	31%	41%
	Electricity from gas	411.3	9%	35%	50%
	Tertiary	278.4	6%	73%	87%
	Final demand	5.4	0%	12%	21%
North-East Europe	Primary	0.5	0%	11%	11%
	Natural gas extract.	0.0	0%	18%	20%
	Other energy extr.	0.0	0%	19%	19%
	Secondary	44.5	1%	18%	18%
	Electricity from gas	79.7	2%	81%	81%
	Tertiary	1.0	0%	6%	6%
	Final demand	4.1	0%	13%	13%

Source: Authors' calculations; base model solution, which is very close to the original data from the EXIOPOL database.

[a] In total 48% of Russian natural gas flows to EU regions.

values. In addition, the initial market equilibrium, from which the optimization procedure starts, is updated to the outcome of the base scenario. For each scenario this procedural starting IRIOT is adjusted such that the cells directly affected by the scenario according to Eq. (5) are already set equal to zero, in order to speed up the convergence of the non-linear programming algorithm.

To better interpret the results of the disruption scenarios, Table 4 summarizes the role of the Russian natural gas in the base scenario. The first two columns show the importance of the various buyers from a Russian perspective. They show that, especially, South-West Europe and East Europe are important buyers of the Russian gas, while most natural gas flows to the secondary sector and the electricity from gas sector. The last two columns of the table show the importance of the Russian gas supplies from the perspective of the buying sectors and regions. It shows that North-West Europe is hardly dependent on imports of Russian gas, due to its availability of large quantities of local natural gas, whereas East Europe is very dependent on Russian natural gas. This is also confirmed by the gas disruption literature, which invariably finds that East Europe is most vulnerable (e.g. Lochner, 2011, Richter and Holz, 2015).

3.2. Trade adjustments in the four scenarios

Given the Leontief technology restriction (2), substitution between products of different sectors is ruled out. However, local products may be substituted for products of the same sector from a different country. We therefore, first, focus on the shift in trade shares in each gas export ban scenario.

3.2.1. Import patterns for each of the regions under all scenarios

To assess the impact on trade patterns, we study the import and self-sufficiency shares (in short: import shares) for each region-sector combination for the base model and for each scenario. These shares are defined relative to the total use of the product at hand as shown in Eq. (6). This allows us to focus on the geographical origin of the inputs from the natural gas sector.

$$t_{ij}^{rs} = z_{ij}^{rs} / \sum_r z_{ij}^{rs}, \quad tf_i^{rs} = f_i^{rs} / \sum_r f_i^{rs} \tag{6}$$

Table 5 shows these intermediate demand and final demand import shares under the various scenarios. The supply of natural gas from North-East Europe is not shown, as it equals zero in all cases.

For North-West (NW) Europe and South-West (SW) Europe, respectively, Table 5-A and Table 5-B show that the trade patterns for these regions do not change much, even if they are fully cut off from Russian gas. In Table 5-B, we see that SW Europe relies most on NW Europe and Rest of the World for its intermediate gas supplies. The final demand import shares react notably different from the inter-

Table 5
Intermediate and final demand import shares of natural gas for each affected region.[a]

5-A	Intermediate demand import shares					Final demand import shares				
North-West Europe	B. Sc.	**Sc. 1**	Sc. 2	Sc. 3	**Sc. 4**	B. Sc.	**Sc. 1**	Sc. 2	Sc. 3	**Sc. 4**
North-West Europe	99.4	99.4	99.4	99.4	99.4	99.2	99.1	99.2	99.1	99.2
South-West Europe	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
East Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Russia	0.0	–	0.0	0.0	–	0.0	–	0.0	0.0	–
Rest of the World	0.2	0.3	0.2	0.2	0.2	0.5	0.6	0.5	0.5	0.5

5-B	Intermediate demand import shares					Final demand import shares				
South-West Europe	B. Sc.	**Sc. 1**	Sc. 2	Sc. 3	**Sc. 4**	B. Sc.	**Sc. 1**	Sc. 2	Sc. 3	**Sc. 4**
North-West Europe	44.0	45.1	43.8	42.9	46.0	57.4	58.0	57.3	57.0	58.2
South-West Europe	13.2	14.1	13.3	13.2	13.8	39.2	40.9	39.2	38.9	40.6
East Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Russia	5.1	–	5.2	6.4	–	2.4	–	2.5	3.1	–
Rest of the World	37.7	40.8	37.7	37.5	40.2	1.0	1.1	1.0	1.0	1.1

5-C	Intermediate demand import shares					Final demand import shares				
East Europe	B. Sc.	**Sc. 1**	Sc. 2	**Sc. 3**	Sc. 4	B. Sc.	**Sc. 1**	Sc. 2	**Sc. 3**	Sc. 4
North-West Europe	22.6	39.8	22.4	39.8	21.5	12.2	16.5	12.1	17.4	11.8
South-West Europe	5.7	10.6	5.7	10.7	5.3	10.9	16.2	10.9	15.4	10.5
East Europe	27.3	31.7	27.1	31.7	26.1	41.0	32.2	41.1	32.7	41.2
Russia	36.6	–	37.0	–	39.9	12.1	–	12.4	–	13.4
Rest of the World	7.9	17.9	7.8	17.7	7.2	23.8	35.0	23.6	34.4	23.2

5-D	Intermediate demand import shares					Final demand import shares				
North-East Europe	B. Sc.	**Sc. 1**	**Sc. 2**	Sc. 3	Sc. 4	B. Sc.	**Sc. 1**	**Sc. 2**	Sc. 3	Sc. 4
North-West Europe	54.0	81.6	82.0	50.8	51.8	71.4	80.4	81.7	68.7	69.4
South-West Europe	1.6	2.1	2.0	1.5	1.5	7.9	9.6	9.0	7.7	7.8
East Europe	0.1	0.1	0.1	0.0	0.1	0.3	0.2	0.3	0.2	0.3
Russia	34.7	–	–	38.3	37.5	12.6	–	–	15.8	14.9
Rest of the World	9.7	16.2	15.9	9.4	9.1	7.9	9.8	9.0	7.7	7.7

[a] In scenarios that are bold-faced, the region is directly impacted (zero imports from Russia). This results in definitional zeros that are indicated with a -.

mediate demand import shares; most natural gas is sourced close to home, in NW and SW Europe itself. Scenario 4 shows that, if possible given the production restrictions of Eq. (4), preference is given to NW European gas over additional own production and supplies from the Rest of the World. The share imported from NW Europe is higher in Scenario 4, than in Scenario 1, where also East Europe and NE Europe demand additional gas from NW Europe.

For East Europe, Table 5-C shows that the reliance on Rest of the World increases relatively most, followed by SW Europe and only then NW Europe. Still, instead of Russia, NW Europe is the largest supplier for the scenarios under which East Europe is directly affected. For the scenarios where the region is not directly affected, the supply share of NW Europe actually decreases somewhat.

North-East Europe in Table 5-D is a special case. Four of the five countries of this region (the Baltic States and Finland) are almost fully dependent on Russia for their gas supplies,[5] whereas Sweden fully relies on gas supplies from NW Europe. Since the natural gas demand in Sweden is relatively high compared to the other four countries, the intermediate and final demand import shares as regards NW Europe are relatively high for this heterogeneous region. The possibility of additional supply from NW Europe will, in the current situation, therefore will actually be lower than shown in Table 5-D.

For the last three scenarios, in the Tables 5-B to 5-D, we see that if a region is not directly affected by the export ban, it will actually import a somewhat larger share of natural gas from Russia, as Russia will look for alternative buyers. Although we abstract from the actual infrastructure capacities, our model thus simulates reality in that it does not allow for an extreme switch to Russian gas because of the assumption that, under each disruption, all economic actors will attempt to maintain as closely as possible their business-as-usual flows.

3.2.2. Change in the supply of natural gas sectors in the different regions

Table 5 considered the spatial origin of the trade in natural gas in the different scenarios. Table 6, instead, focusses on the change in supply of natural gas and its spatial destinations. This table reports these changes as a percentage of the base scenarios total supply of natural gas by producing country.

In Scenario 1, the fall in supply from Russia is clearly largest for SW Europe (−19.31%) and East Europe (−27.75%). Russia itself absorbs some of this fall in exports domestically, as does the Rest of the World to a greater extend (+6.34%). However, the total output of the Russian natural gas extraction sector still falls with as much as −41.42%, which will definitely hurt the Russian economy as will be shown in Table 8. Europe is a very important market for Russia and this high dependence explains Russia's relentless activities to open up alternative markets.

The most notable increase in supply (+11.52%) is the additional percentage that East Europe supplies to itself for both scenarios that affect the region directly. With this increase, East Europe is the only region that hits the maximum production capacity that we defined exogenously in Table 2. In contrast, in the two scenarios where East Europe is not directly hit, the supply of its own natural gas sector falls, as Russia will then sell more to East Europe.

Also remarkable are the changes in the supply of NW Europe, not because they are large, but because they are small. This is the more remarkable because we know from Table 5 that all regions import more from NW Europe when they are affected, especially East Europe and

[5] This was the case for the base year input-output data. Nowadays, Norway's Statoil supplies some 60% of Lithuania's natural gas imports. Parts of these imports also find their way to Latvia and Estonia. Using more recent data, therefore, will result is somewhat different outcomes.

Table 6
Change in sales of the natural gas sector by region of origin, as a percentage of total output.

	Regions of destination of natural gas sales						
	NW	SW	East	NE[a]	Russia	RoW	Total change
Scenario 1: all EU							
NW Europe	−0.55	0.10	1.46	0.25	0.00	−0.10	1.16
SW Europe	0.08	2.08	3.74	0.04	0.00	−0.56	5.38
East Europe	−0.05	−0.21	11.52	−0.01	−0.02	−1.23	10.00
Russia	**−0.06**	**−19.31**	**−27.75**	**−2.94**	2.31	6.34	−41.42
Rest World	0.00	0.31	0.21	0.01	−0.11	−0.30	0.12
Scenario 2: NE Europe							
NW Europe	−0.05	−0.12	−0.02	0.25	0.00	−0.01	0.06
SW Europe	0.00	−0.01	−0.02	0.04	0.00	0.06	0.07
East Europe	0.00	0.00	−0.52	0.01	0.00	0.01	−0.49
Russia	0.00	0.50	0.36	**−2.94**	0.13	0.24	−1.70
Rest World	0.00	0.00	0.00	0.01	−0.01	−0.01	0.00
Scenario 3: East Europe							
NW Europe	−0.33	−0.66	1.45	−0.03	0.00	−0.02	0.41
SW Europe	0.02	−1.48	3.78	−0.01	0.00	0.07	2.39
East Europe	−0.04	−0.20	11.52	−0.02	−0.02	−1.24	10.00
Russia	0.02	4.90	**−27.75**	0.32	1.00	2.56	−18.94
Rest World	0.00	−0.02	0.21	0.00	−0.05	−0.11	0.03
Scenario 4: SW+NW							
NW Europe	−0.22	0.63	−0.09	−0.02	0.00	−0.02	0.28
SW Europe	0.00	1.77	−0.29	0.00	0.00	0.18	1.66
East Europe	0.01	0.03	−3.56	0.00	0.00	0.17	−3.35
Russia	**−0.06**	**−19.31**	2.64	0.25	0.71	1.80	−13.98
Rest World	0.00	0.25	−0.01	0.00	−0.04	−0.13	0.06

Note: the changes that are bold-faced represent the values that are set to zero. In all cases where the 2-digit value is equal to 0.00, a minus sign is included if the (small) change is negative.
[a] North-East Europe is not included as a row in the different scenarios due to the non-existing gas extraction.

North-East Europe. The explanation is that the domestic use of natural gas in North-West Europe is large compared to the demand from the other regions, which makes the percentage point changes in its exports small.

Comparing the sum of the different scenarios in which a subset of the regions is affected (Scenarios 2–4) with Scenario 1, the sum of the 'individual' scenarios generally turns out to be smaller than the changes in supply in Scenario 1. When the shock is smaller, there is obviously more flexibility in finding substitute sources of supply then when all regions are hit simultaneously.

3.2.3. Impacts on the trade balances

The previous sections investigated the changes in trade shares for the natural gas sector only. To place these changes in perspective, the changes in the trade balance for each region, in constant base scenario prices, are presented here. The balance for each region is calculated as follows.

$$b^s = \sum_{r\neq s,\quad i,j} z_{ij}^{sr} + \sum_{r\neq s,\quad i} y_{i.}^{sr} - \sum_{r\neq s,\quad i,j} z_{ij}^{rs} - \sum_{r\neq s,\quad i} y_{i.}^{rs} \tag{7}$$

In Table 7, the first column shows the balance for each region in the base scenario, in absolute values. The total of this column equals zero, because total exports equal total imports at the world level. For Russia, the export ban to all of Europe (Scenario 1) has a relatively large negative impact on the value of its trade balance, which is now less positive than in the base scenario. The trade surplus of NW Europe and SW Europe increases in all scenarios. Most remarkable, however, is the relatively small size of the impacts on the trade balances of all scenarios. This raises the question whether the impact on welfare indicators such as GDP and total final demand will be comparably small.

Table 7
Balance of payments, percentage change compared to base scenario.

	B. Sc. (M €)	Sc. 1	Sc. 2	Sc. 3	Sc. 4
North-West Europe	74,110	0.74%	0.05%	0.32%	0.22%
South-West Europe	27,469	1.65%	0.05%	0.69%	0.84%
East Europe	−32,866	−0.41%	0.03%	−0.49%	0.17%
North -East Europe	26,185	−0.03%	0.06%	−0.06%	−0.05%
Russia	45,194	−3.12%	−0.13%	−1.41%	−1.05%
Rest of the World	−140,092	−0.20%	0.00%	−0.05%	−0.11%

3.3. Impact on value added

The changes in trade patterns in Tables 5 and 6 influence value added generated in each region-sector. Table 8 shows the change in value added, in constant base scenario prices, for the three smaller sectors for each region separately. The three large sectors (primary, secondary and tertiary) are only represented indirectly by the total change of GDP, because the changes in terms of inputs from the natural gas sectors, and other shifts in the input structure, are relatively small compared to the overall size of these sectors.

Alike the changes in trade shares, we see again that the overall change in value added for Scenario 1 is larger than the sum of the changes in the three sub-scenarios. Clearly, in the case of a complete Russian gas export ban to the entire EU, fallback systems, where other regions step in for the loss of Russian supply, are also hit, including the feedback loops between these systems, resulting in a larger overall impact than with the sum of the partial export bans.

At the level of the three small sectors, the behavior of the gas extraction sector, on the one hand, and the other energy extraction and the electricity from gas sectors, on the other hand, is opposite in almost all cases. The equal signs of the changes for both the other energy extraction sector and the electricity sector indicate that the theoretical possibility of indirect technical substitution does occur in our model simulations. The aggregate character of the other three sectors, obviously, prevents this indirect substitution to dominate the direct technical complementary assumed in Eq. (2).

The opposite sign of the changes in the electricity from gas sector and the gas extraction sector requires a longer explanation. The increases in local gas extraction in the EU regions, in fact, occur to compensate for the drop in Russian imports, but this compensation appears to be partial, and, therefore, it is combined with an opposite change in the use of gas by the electricity from gas sector. The case of East Europe is especially interesting in both cases where it is not itself subject to a Russian export ban, i.e., in the Scenario´s 2 and 4. In those cases, Russia will increase its exports to East Europe, its largest customer in the EU, in order to compensate for its losses in the rest of the EU. Consequently, we see an increase in the output of the electricity from gas sector in East Europe combined with a decrease in its home extraction of natural gas.

Furthermore, in all scenarios, we see that the change in the local natural gas extraction sector determines the sign of the change in total volume of GDP for almost all regions. Higher order spatial substitution processes mitigate the direct impact on the natural gas extraction sector, but do not change the sign of its impact on total value added. The exception is North-East Europe that does not have a natural gas extraction sector. In that case, we see that the change in the secondarily impacted sector, i.e., the electricity from gas sector, determines the sign of the total GDP impact.

As to the size of the total GDP impact, the only region that really suffers from the export bans is Russia itself, but even that impact is almost negligible at the level of the macro economy, i.e., – 0.5% in case of the maximum supply shock of Scenario 1.[6] NW and SW Europe profit from all four types of export bans, but their gains are both absolutely and percentagewise much smaller than the already small losses for Russia.

Table 8
Percentage change in value added in the gas-related sectors and the total economy.

	NW	SW	E	NE	Russia	RoW
Scenario 1: all EU						
Natural gas extraction	1.16	5.38	10.00	–	−41.42	0.12
Other energy extraction	−0.02	−0.01	−0.07	−0.07	0.01	−0.00
Electricity from gas	−0.28	−0.47	−7.50	−8.48	1.74	−0.05
Total value added	0.01	0.00	0.00	−0.00	−0.50	0.00
Total absolute change[a]	320	150	18	−9	−1280	105
Scenario 2: NE						
Natural gas extraction	0.06	0.07	−0.49	–	−1.70	0.00
Other energy extraction	−0.00	0.00	0.00	−0.16	0.00	−0.00
Electricity from gas	0.01	−0.00	0.19	−8.18	0.25	−0.00
Total value added	0.00	0.00	−0.00	−0.00	−0.02	0.00
Total absolute change[a]	16	2	−2	−7	−52	1
Scenario 3: E						
Natural gas extraction	0.41	2.39	10.00	–	−18.94	0.03
Other energy extraction	−0.01	0.00	−0.06	0.04	0.01	−0.00
Electricity from gas	−0.13	0.09	−7.98	0.52	0.46	−0.01
Total value added	0.01	0.00	0.00	0.00	−0.23	0.00
Total absolute change[a]	113	80	20	0	−588	28
Scenario 4: SW+NW						
Natural gas extraction	0.28	1.66	−3.35	–	−13.98	0.06
Other energy extraction	−0.01	−0.00	0.00	0.01	0.00	−0.00
Electricity from gas	−0.09	−0.35	1.25	0.38	0.26	−0.03
Total value added	0.00	0.00	−0.00	0.00	−0.17	0.00
Total absolute change[a]	77	37	−14	0	−435	47

[a] In absolute M€ compared to base model.

Table 9
Change in the final consumption of natural gas, in percentages.

	B. Sc. (abs. M€)	Sc. 1	Sc. 2	Sc. 3	Sc. 4
North-West Europe	2533	−8.2	−0.8	−4.7	−3.4
South-West Europe	3075	−7.7	−0.6	−4.0	−4.8
East Europe	44	−32.5	−0.1	−32.2	2.6
North-East Europe	32	−16.7	−13.1	0.2	−1.0
Russian Federation	21	46.2	1.2	15.3	9.3
Rest of the World	26,674	−0.9	0.0	−0.2	−0.4

Table 10
Change in total final consumption, in percentages.

	b.sc abs 1000 M€	Sc. 1	Sc. 2	Sc. 3	Sc. 4
North-West Europe	2166	−0.011	−0.001	−0.006	−0.004
South-West Europe	5524	−0.005	0.000	−0.002	−0.004
East Europe	717	−0.016	0.001	−0.020	0.006
North-East Europe	355	0.000	−0.006	0.005	0.004
Russian Federation	212	0.062	0.002	0.024	0.018
Rest of the World	25,027	−0.001	0.000	0.000	0.000

3.4. Impact on total domestic consumption

As a second measure of welfare, next to value added, and in fact even more relevant for domestic welfare, we also look at the impact of the four scenario´s on domestic final demand, in constant base scenario prices.

The changes in the underlying final demand import and self-sufficiency shares of the directly impacted gas extraction sector were shown in Table 5. The associated impact on the volume of the final consumption of natural gas, irrespective of its geographic origin, is shown in Table 9. Again note that the impact of the sum of the Scenario´s 2–4 is smaller than the impact of the combined Scenario 1. Furthermore, it is obvious that the domestic consumption of the more abundant natural gas in Russia will increase in all scenarios, whereas the natural gas consumption of the European regions decreases in almost all cases.

Interesting are the two plusses. Take the +2.6% of the consumption of natural gas in East Europe in case of a supply shock in SW and NW Europe (Scenario 4). East Europe being near, obviously, serves as a substitute market for Russian gas in that case. The same holds for the +0.2% increase in North-East Europe, in case of a supply shock in East Europe (Scenario 3). The most puzzling outcome of Table 10 seems to be the decrease in the consumption of natural gas in the RoW. However, this can also be explained easily. The strong increase in the exports of natural gas from the RoW to the boycotted regions of Europe, induced by the higher prices there, partly goes at the cost of their local consumers.

Finally, consider Table 10 that shows the impacts of the four scenarios on the welfare of the population of the regions involved. Remarkably, in contrast with the negative impact on GDP, the Russian population will benefit from the Russian refusal to export its natural gas to parts or the whole of the EU. Part of the reason for this outcome is the increase of the domestic consumption of natural gas shown in Table 9. Note that this increase may postpone the necessary reduction of the inefficiencies in the Russian domestic use of energy (see Proskuryakova and Filippov, 2015). These inefficiencies are partly explained by the low prices of energy, which will be further lowered in each of the four scenarios. These longer term negative externality impacts on Russian welfare are not considered in our simulations, as they run aside of the market transactions in Eq. (2). The other part of the reason for the domestic welfare increase is summarized in Table 7, which shows a decrease of Russia´s trade balance surplus, which enables Russian consumers to consume more of the negatively

[6] For reference: in the base year input-output data the share of value added of Russian natural gas extraction in total Russian value added (GDP) was 1.21%.

impacted domestic value added. Whether this decrease in the balance of payments is sustainable in the longer run may be doubtful, but in the short to medium run, which is the focus of our model, this impact is quite likely.

The reverse impact may be observed for most European regions with most scenario´s. There, increases in total value added, concentrated in the local gas extraction sector, go together with decrease of total domestic consumption. Again, part of the reason is found in the lower consumption of natural gas shown in Table 9, induced by the higher gas prices, and another part of the reason is found in the more positive trade balances in Table 7.

4. Conclusion and policy implications

In this paper we have analyzed several scenarios related to reductions or obstructions in the supply of natural gas across country borders. The pattern of impacts found with our new modelling approach reflects the partially compensating and partially enhancing simultaneous forces of supply and demand and spatial substitution effects. At the lower levels of aggregation, for example, as regards the import and self-sufficiency shares for the use of natural gas, considerable effects are found. At the aggregate level of the whole economy, however, the effects of Russian natural gas export bans are negligible for Europe and only a little less so for Russia itself. Interestingly, the effects on the size of the economy, as measured by its GDP, are predominantly positive for the European regions, but negative for Russia. The effects on the welfare of the populations involved, however, as measured by the size of the domestic final demand, have an opposite sign; with predominantly negligible but negative effects for the European regions, and very small, but positive effects for the Russian population.

In view of this empirical conclusion, the question arises whether the outcome of negligible impacts of various Russian export stops is not overly optimistic and due to the aggregate character of the present simulations. First, consider the sectoral aggregation used in this application. Having a further disaggregation of sectors that use natural gas intensively might show vulnerabilities that now remain undetected. On the other hand, however, separating the electricity production based on other energy carriers from the secondary sector and allowing for technical substitution between the different types of electricity will introduce more flexibility, and thus mitigate the presently predicted negative forward effects from electricity on the secondary sector.

Second, consider the spatial aggregation used in this application. Having a further disaggregation between the different EU member states will allow modelling the fragmentation of the EU natural gas market by introducing bilateral trade capacity constraints, which reflect the actual natural gas pipeline capacities. The model then would not depict the presently assumed full flexibility of the interregional EU natural gas trade, which will most certainly lead to several eastern EU-countries being hurt more and maybe some northwestern EU-countries being hurt less than is shown in the present simulation outcomes. In any case, this new modelling approach appears to be promising and, for the moment, confirms the EU expectation that it could cope well with the consequences of a Russian gas boycott.

Finally, note that the scenarios presented in this paper are rather generic. For more specific analyses, and in order to take into account pipeline infrastructure capacities, our model could relatively easily be combined with a more detailed model for the natural gas sector. The results of this more detailed model, in terms of the optimal gas production levels and gas flows, could be introduced as constraints in the present model. This would make it possible to compute the wider economic impacts of the optimal solution that results from the sector model.

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Appendix A. Data aggregation

Country aggregation

North-West Europe		**North-East Europe**	
(5 countries)	Denmark	(5 countries)	Estonia
	Ireland		Finland
	Netherlands		Latvia
	Norway		Lithuania
	United Kingdom		Sweden
South-West Europe		**Russian Federation**	
(9 countries)	Belgium	(1 country)	Russia
	France		
	Germany	**Rest of the World**	
	Italy	(13 countries	Australia
	Luxembourg	+ original RoW region)	Brazil
	Malta		Canada
	Portugal		China
	Spain		India
	Switzerland		Indonesia

		Japan
East Europe		Mexico
(10 countries)	Austria	South Africa
	Bulgaria	South Korea
	Cyprus	Taiwan
	Czech Republic	Turkey
	Greece	United States
	Hungary	Rest of World (region)
	Poland	
	Romania	
	Slovak Republic	
	Slovenia	

Sector aggregation

Code	Aggregate sector	Aggregate sector	# of subsectors
i01.a – i05	Primary sector	Primary sector	27
i10	Other energy extraction	Natural gas extraction	1
i11.a	Other energy extraction	Other energy extraction	4
i11.b	Natural gas extraction	Secondary sector	62
i11.c	Other energy extraction	Electricity from gas	1
i12	Other energy extraction	Tertiary sector	34
i13.1 – i14.3	Primary sector		
i15.a – i40.11.a	Secondary sector		
i40.11.b	Electricity from gas		
i40.11.c – i45	Secondary sector		
i50.a – i99	Tertiary sector		

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